

Final Project Report to the NYSIPM Program, Agricultural IPM 2003-2004

Project type: Research and Development; Continuing

Title: Developing Damage and Economic Thresholds for Foliar Disease Management in Perennial Plantings of Strawberry

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Abstract

Leaf scorch, leaf spot, and leaf blight are foliar diseases of strawberry encountered commonly in perennial plantings in New York. The extent of direct losses attributable to these diseases is not known, but high levels of disease reduce the area of photosynthetically active foliage, weakening the plant and affecting winter hardiness and yield in subsequent seasons. Many growers do not manage foliar disease after harvest because the economic benefits of doing so are unclear. To begin to assess the value of foliar disease management, we measured the impact of disease on photosynthesis on individual leaves. For leaf scorch and leaf spot, photosynthesis decreased linearly with increasing disease severity beginning with very low levels of incidence. Mutisya and Sullivan (1994) showed that appreciable yield reductions occurred when leaf scorch severity reached approximately 45% by seasons end. In our study, leaflets with 45% leaf scorch suffered approximately a 50% reduction in photosynthesis; our preliminary analysis suggests that this reduction is achieved with 30% leaf spot. This could indicate that when photosynthesis is reduced by 50%, whether it is by leaf scorch, leaf spot, leaf blight, or any other foliar pathogen, yield is affected. We are currently conducting field studies to validate these laboratory results.

Background and Justification

Leaf scorch, leaf spot, and leaf blight are foliar diseases of strawberry encountered commonly in perennial plantings throughout North America (Ellis, 1995; Ellis, 1998; Xue et al, 1996). Depending upon weather conditions, disease severity reaches its peak at harvest or after renovation on June bearing varieties. The extent of direct losses attributable to these diseases is not known, but high levels of disease reduce the area of photosynthetically active foliage, weakening the plant and affecting winter hardiness and, quite possibly, yield in subsequent seasons. Furthermore, it is unclear what affect recurring annual epidemics have on the production life of a perennial planting. The typical production life of a perennial matted row planting is 4 years, but it is unknown whether this can extend beyond 4 years if these diseases were managed in the field.

Strawberry leaf spot is caused by the fungus *Mycosphaerella fragariae* (anamorph *Ramularia brunnea*) and is one of the most common and destructive diseases of cultivated strawberry worldwide (Maas, 1984; Nemec, 1972). Black seed, a serious disease of strawberry, occurs when *M. fragariae* affects the fruit (Maas, 1984). The causal agent of leaf blight is the fungus *Phomopsis obscurans* (Ell. & Ev.) Sutton. In years of high disease pressure, infections may occur on stolons, petioles, and fruit (Howard and Albregts, 1973). Leaf scorch is caused by the fungus *Diplocarpon earlium* (Ell. & Ev.) Wolf; the disease is not known to affect the fruit directly like the previous two diseases. The three diseases are relatively simple to distinguish from each other by their symptoms, even when found on the same leaflet.

All three pathogens overwinter in diseased tissue and leftover crop debris. In spring, they become active and produce inoculum to initiate epidemics. *M. fragariae* typically affects young, expanding leaves and petioles. *D. earlium* affects leaves and petioles of virtually all ages, but damage tends to be most severe when infections begin early (Turechek et al., 2003). *P. obscurans* primarily attacks younger leaves, but symptoms are slow to develop and are generally evident only on mature leaves (Nita et al., 2003). Secondary cycles of infection are possible for each of these diseases and can continue through most of the growing season when conditions favor infection and disease development. All three pathogens require free moisture for infection to occur. The optimum temperature for infection and disease development is in the range of 15 and 25 C for leaf spot and leaf scorch. Temperature plays a less important role for leaf blight, but a heat shock is necessary for symptom development under controlled and, one can assume, field conditions (Nita et al., 2003).

Recently we characterized the relationship between the severity of infection by *D. earlium* and its impact on photosynthesis of individual leaves and found that photosynthesis decreases linearly with disease severity beginning with very low levels of incidence (Turechek et al., 2003); this will be discussed in greater detail below. Mutisya and Sullivan (1994) inoculated plants with different concentration of *D. earlium* during flower bud differentiation and found a negative correlation between disease severity and yield. Specifically, leaf scorch impacted the health and production of new crowns. Significant yield reductions were apparent when disease severity at seasons end reached approximately 45% in their experimental plantings. Not surprisingly, yield was not reduced with low levels of disease, despite a reduction in photosynthesis. The worst treatment, with 80% scorch by seasons end, suffered a 25% reduction in yield the following season.

Many growers are reluctant to apply fungicides to control foliar diseases after harvest because the economic benefits of doing so are unclear. Simply, the cost of applying a fungicide with good broad-spectrum activity against foliar diseases, such as Cabrio EG or Nova 40W, must be compensated by an equal increase in revenue. This could be manifested as either an increase in yield the following season, an extended life of the strawberry planting, or a combination of the

two. Furthermore, it is unclear how to best manage these diseases. Extensive review of the literature showed a paucity of information on strawberry foliar pathogen biology in regard to the timing of applications to achieve best foliar disease control. It is suggested by some researchers that applications immediately following straw removal were critical for leaf scorch. Spot control, it is suggested, is necessary just before and during bloom. Other researchers indicate post-renovation control is essential for both blight and scorch.

To assess the value of foliar disease management, a 3-year project was designed to measure the impact of leaf blight, leaf spot and leaf scorch on the productivity of a perennial matted row planting.

Objectives

- (1) Determine the effect of leaf spot, leaf blight, and leaf scorch on the rate of photosynthesis in strawberry leaves under greenhouse conditions;
- (2) Determine the cumulative effect of foliar pathogens on strawberry yield in perennial matted-row field plantings of strawberry; and
- (3) Develop an economic basis for managing foliar disease based on the relationship among disease severity, photosynthetic rate, and strawberry yield.

Procedures

OBJECTIVE 1: Plant Production: Initially, we grew dormant runner plants in a 4:1 mixture of Cornell mix and sand, fertilizing them in weekly alternation with Peter's calcium nitrate (15:0:0) and Peter's Peat-lite fertilizer (20:10:20) with micronutrients to provide plants with 100 ppm N per week. Eventually, we began propagating our own plants from runners. Runner plants were more uniform in age, produced similar sized plants, and suffered from fewer disorders. Plantlets were established in Cornell Mix and sand mix at (6:1), rather than the initial (4:1) ratio, and fertilization was reduced to 50 ppm N per week due to the high soluble salt content of our water source. Because the susceptibility of leaves to infection is affected by leaf age, newly expanded leaves were tagged and dated daily so leaf age at inoculation could be documented (Nita et al., 2003; Zheng and Sutton, 1994).

Inoculum Production and Inoculation: All pathogens were isolated from symptomatic leaf tissue and maintained on potato dextrose agar. To ensure that isolates maintained their pathogenicity, they were never permitted more than three successive transfers on artificial media. When isolates reached their transfer limit, they were introduced back in to strawberry and re-isolated from diseased tissue. Plants of cultivar 'Honeoye' or 'Kent' were inoculated with a 1×10^5 conidia / ml aqueous suspension of the leaf scorch pathogen *Diplocarpon earliarum* using a hand-held atomizer. Inoculated plants were placed in misting tent maintained at 100% RH for 0, 24, 48, 72, or 96 hrs. By exposing plants to different leaf wetness periods we were able to produce a range of disease severities. After the prescribed period of misting, plants were removed to a greenhouse bench to allow disease development. Initial symptoms typically appeared 3-5 days after inoculation at 70-75 F. Leaf spot (*M. fragariae*) experiments were carried out on 'Kent' plants under the same experimental conditions and inoculum levels as described above; initial symptoms appeared 7-10 days post-inoculation. Leaf blight (*P. obscurans*) experiments were carried out on 'Jewel' plants in the same manner at inoculum levels of 1×10^6 conidia/ml and under slightly modified incubation conditions described below; time to symptom expression varied, depending on post-inoculation incubation temperatures.

Photosynthesis Studies: Most of our photosynthesis work has been done with leaf scorch. This is because this was the pathogen we were able to first develop protocols for culturing and inoculation that produced repeatable results. Studies are continuing with the leaf spot pathogen, as we have recently developed working protocols for this pathogen; work with leaf blight is progressing.

Several factors were considered in measuring photosynthesis. First, we needed to develop a standard set of conditions for measuring photosynthesis. Plants assimilate CO₂ in a saturation-type reaction in response to light (irradiance); that is, there is a maximum value of irradiance at which any increase above this maximum does not result in an increase in assimilation of CO₂. In controlled studies, it is desirable to work at this maximum value of irradiance or above so that any fluctuation in photosynthesis can be attributed to treatment effects rather than a plants response to changing irradiance values. Leaves from uninoculated plants and asymptomatic leaves from plants inoculated with *D. earliana* were exposed to a range of irradiance (*I*) values to determine the value of *I* at which light saturation occurs (i.e., where photosynthesis peaks). Rate of assimilation (*A*), i.e., rate of CO₂ uptake ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), and rate of H₂O transpiration (*E*) ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) were measured on individual leaflets with a broad leaf (large) cuvette and a narrow leaf (small) cuvette.

We used both cuvettes to determine which of the two would be preferable for use in future studies. There are pros and cons associated with each style cuvette. The larger cuvette covers a greater leaf area and could possibly be more accurate in gauging the relationship between disease severity and photosynthetic rate than with the small cuvette that encompasses a set leaf area (2 cm circle). The area encompassed by the large cuvette is large enough to permit a direct measurement of disease severity within the chamber it encloses. However, a single measurement taken with the large cuvette takes nearly three times as long to record than a single measurement taken with the small cuvette.

For each leaflet assessed (i.e., diseased or healthy), 3 measurements were taken: (1) a single reading from leaflet #2 with broad leaf (large) cuvette (Figure 1); (2) a single reading from leaflet #2, position 'A' with a narrow leaf (small) cuvette; or (3) three readings from leaflet #2 at locations 'A-C' with a small cuvette. All measurements were made with a CIRAS (PP Systems, Inc.) photosynthesis meter under constant irradiance (PAR [photosynthetically active radiation] of 350 $\mu\text{mol m}^{-2} \text{ s}^{-1}$) and temperature. The leaflets were detached after the readings were taken and the proportion of leaflet area diseased was calculated with the digital imaging software ASSESS (APS Press) from leaflet images that were scanned with an Acer ScanPris flatbed scanner at 100DPI. In addition, the proportion of leaflet area diseased from the portion of leaflet enclosed by the broad leaf (large) cuvette was calculated by cutting away excess leaflet tissue that was not enclosed within the chamber and creating a digital image as above.

OBJECTIVE 2: Research plots were established at two locations: 1) a research planting of the variety 'Jewel' established in 1999 on the property of the Cornell Research Farm in Ithaca, NY; 2) research plantings of the varieties 'Jewel' and 'Kent' established at the New York State Agricultural Experiment Station in Geneva, NY in 2001. All plantings were planted in a matted-row system on 4-ft centers. Individual plots within plantings consisted of 12 ft row sections with a 3 ft buffer section on each end.

To generate different levels of foliar disease across the plots, the fungicides Nova 40W or Captan 80W were applied at various rates (see 'treatments' in Tables 1-4). In 2001, only the 'Jewel' planting in Ithaca was harvestable (the Geneva plantings were in their establishment year). In 2002, strawberries were harvested and weighed from each plot to provide a measurement of crop yield. Harvesting ceased when the average berry weight per plot fell below 8 g. Biomass was assessed by mowing and bagging all the leaves from within each plot separately, placing the bags in a greenhouse to allow the leaves to dehydrate (approx. 2

months), and weighing the dried leaves. Crown counts were counted for each plot shortly after the leaves were mowed off (Table 1). Disease incidence was rated in each plot just prior to renovation (harvest) in mid summer (except in 2001), and again in late fall after establishment of the new crowns.

Fungicides and application timings were modified in 2003 because: 1) we were unable to generate the differential levels of disease with first protocol; and 2) the new protocol would permit us to evaluate the efficacy of early, late, and full season schedules for management of foliar disease. The revised schedule is outlined in Table 5.

Disease incidence data were arcsine square root transformed; berry weight, biomass, and crown count data were log transformed. Transformed data were analyzed in an ANOVA using SAS PROC MIXED and treating 'block' as a random effect. Treatment means were separated using the pairwise difference option (PDIFF) in PROC MIXED ($P < 0.05$).

Results and Discussion:

OBJECTIVE 1: Assimilation/Irradiance Curve: Figures 2a and 2b show the relationship between A and I for cultivars Jewel (closed bullets) and Kent (open bullets) for the large and small cuvettes, respectively. A increased proportionally with I , specifically PAR (i.e., photosynthetically active radiation), up to approximately $350 \mu\text{mol photons m}^{-2} \text{s}^{-1}$ after which A leveled off. This response was independent of variety. At any given level of I , however, A was variable. Some of this variability may be explained by leaf age, as very young and very old leaves tend to be the most variable. In general, healthy leaves less than 10 days old had lower A than all other healthy leaves. Leaves from 11 days to more than 60 days in age, while showing some variation in A , were comparable. Leaves older than 60 days tended to show a decrease in A . Based on these results (and practical limitations), all further experiments were carried out in a biotron under near constant I ($350 \mu\text{mol photon m}^{-2} \text{s}^{-1}$) and temperature (22 C) to ensure uniform photosynthesis measurements at near saturation levels of I .

Cuvette Comparison: There was nearly a two-fold difference in magnitude for both A and E between the 2 cuvettes (E data not shown), despite the similarities in shape of the response curve (Fig. 2A, B). Why this occurred is not completely understood. Positional and/or edge effects may affect measurements taken with the large cuvette since it encloses the distal end of the leaf. Leaf edges tend to suffer the most damage from salt accumulation, common in greenhouse-grown plants. There are generally fewer stomata at the leaf edge, which may also be a contributing factor. The large cuvette enclosed the entire upper portion of the leaf, including margins, than those taken with the smaller cuvette, which include very little if any leaf margin.

Measurements on healthy leaflets whether on leaflet positions 1, 2 or 3 showed no significant differences in either A or E (E data not shown). Figure 3A shows the relationship between measurements of A taken with the large cuvette (A_L) and corresponding measurements taken with the small cuvette either as a single measurement (A_A) or an average of three measurement on a single leaflet (A_{ABC}). The relationships are linear and statistically equivalent according to regression analysis. Small cuvette measurements using the average of 3 readings were more precise than those for a single reading as indicated by the higher value of r^2 . The relationship between leaf scorch severity within the area enclosed by the chamber of the large cuvette and actual severity of the entire leaflet is shown in Figure 3B. There is a 1:1 correlation between these two measurements indicating either can be used as an accurate measure of disease severity.

The effect of foliar disease on A and WUE for individual strawberry leaflets: Figures 4A-D show the relationship between A and water use efficiency (WUE), calculated as A/E , and disease severity (S) for measurements taken with the large cuvette (A_L , WUE_L) or as an average of three readings taken with the small cuvette (A_{ABC} , WUE_{ABC}). As expected, there was a significant decrease in both A and WUE with increasing disease severity. The best fitting lines are shown on the corresponding figures. The average assimilation rate for uninfected leaves is represented by the intercept term in the regression equations depicted in Figures 4A and B, a 50% reduction in assimilation occurs at approximately 40% and 45% disease severity with readings taken with the small and large cuvettes, respectively. A similar result was obtained with field data (data not shown). This level of disease severity corresponds to the minimum level of disease Mutisya and Sullivan (1994) showed to begin to impact yield.

Photosynthesis studies with *M. fragariae*: Initial infection experiments with leaf spot were very successful. However, the pathogen lost its pathogenicity or its sporulation capacity after 2 to 3 successive transfers in culture, necessitating re-isolation from infected tissue each time prior to carrying out the next infection experiment. Procedures are now in place to carry out photosynthesis experiments with this pathogen, but they are proceeding at a slower rate than those of *D. earlium*, as they require re-isolation at frequent intervals. Initial results show a similar trend in the relationship between disease severity and assimilation found with *D. earlium* (Figure 5). However, we are not certain that this relationship is best represented by a linear model; additional investigation in to the appropriate model is underway.

Photosynthesis studies with *P. obscurans*: Infection experiments with leaf blight brought few results initially as symptoms took 6-8 weeks or more to be expressed under greenhouse conditions and these were not characteristic of field symptoms. After several months of experimentation, we were able to determine that a high post-infection temperature is critical to uniform and rapid symptom expression (26-28 C). Further work with *P. obscurans* will include a 7-day "heat shock" treatment 1-week post inoculation to speed symptom development.

OBJECTIVE 2: Ithaca Planting (Jewel): No significant differences were observed among treatments for any of the harvest data (i.e., fruit weight, plant biomass, and crown count) in 2001 or 2002 (Table 1), despite minor differences in leaf blight incidence among fungicide treatments in fall of 2001 and spring of 2002 (Table 2). This 3-year-old 'Jewel' planting was vigorous coming into harvest in 2002 and yield in control plots was comparable with 2001. Regrettably, a large proportion of the fruit harvested was infected with leather rot (*Phytophthora cactorum*). After renovation many crowns were weak or dead and regrowth of the planting was slow. In some instances, the 12 ft plot sections contained as few as 12 viable crowns after renovation. The ensuing drought further weakened affected plants resulting in large areas of dead plants in each row. We discontinued the work in this planting as it remained very weak in spring 2003; these factors would have confounded future results.

Geneva Plantings (Jewel and Kent): In 2002, foliar disease incidence was relatively low in the 'Kent' planting at harvest (Table 4). The incidence of leaf scorch in the 'Jewel' planting, however, was high during harvest due to the placement of potted, leaf-scorch-infected plants in the border sections of the planting in early spring. Unfortunately, we were unable to generate a gradient of disease incidence across the plots using the prescribed fungicide schedule (Table 4). The Geneva plantings were harvested for the first time in 2002. Despite the moderate incidence of leaf scorch, no or only minor significant differences in harvest data were seen among fungicide treatments in 2002 in both the 'Kent' and 'Jewel' plantings (Table 3). Leaf blight incidence increased in all plots after harvest but, again, we were unable to generate a distinct disease gradient across the treatments. Consequently, there were no or only minor significant differences in harvest data were seen among fungicide treatments in 2003 in both the 'Kent' and 'Jewel' plantings (Table 3).

At this point we abandoned the current protocol in lieu of a simpler and more interesting fungicide schedule. We altered our fungicide regimes to generate only 3 levels of foliar disease (low, medium, and high) as we found it difficult to manage disease to produce seven, statistically distinct levels of disease as was originally planned. Furthermore, we found it difficult to manage our plantings so that only the disease of interest develops. Additionally, other foliar pathogens, particularly powdery mildew, caused by *Sphaerotheca macularis*, and angular leaf spot, caused by the bacterial pathogen *Xanthomonas fragariae*, became established in our plantings. In view of these developments, we broadened the focus of our field trials to look at the cumulative effect of foliar disease on yield and yield components, rather than on any particular pathogen or set of pathogens during the growing season.

Essentially, the 42 original plots (i.e., 7 treatments x 6 replications) were reassigned to the new treatments (4 treatments x 10 replications)(Table 5); in so doing, we were able to retain the yield data from each of these plots. The treatments outlined in Table 5 were applied at the start of the 2003 season. The harvest data from these plots was statistically equivalent across all parameters measured. Fortunately, we were able to generate 3 and 4 statistically different levels of disease in the 'Kent' and 'Jewel' plantings, respectively. Moreover, the predominant disease in the 'Kent' planting was scorch and blight in the 'Jewel' planting. We project we will be able to collect the first definitive return yield data during the 2004 season as significantly different levels of both blight and scorch were achieved in 2003.

OBJECTIVE 3: This objective still needs to be addressed once sufficient data has been collected from objectives 1 and 2. An Excel budgeting workbook, prepared by Regina Rieckenberg and Alison DeMarree, and cost information are already in place for economic analysis. We expect to have the full set of data in hand for the completion of this objective by fall 2005. We will however, begin exploring options in spring 2004 once the leaf spot data set is complete.

Conclusion:

Despite the setbacks we encountered during the first year of the project, the funding we received over the past 3 years from the NY IPM program has helped us to develop a better understanding of the impact of foliar disease on strawberry production. We were able to demonstrate a strong negative linear correlation between measurements of photosynthesis (i.e., *A* and *E*) and the incidence of leaf scorch. Our initial results indicate that a very similar relationship exist for leaf spot affected plants. The results of Mutisya and Sullivan (1994) showed that appreciable yield reductions occur when leaf scorch severity reached approximately 45% by seasons end. In our study, leaflets with 45% leaf scorch suffered approximately a 50% reduction in photosynthesis. This could indicate that when photosynthesis is reduced by 50%, whether it is by leaf scorch, leaf spot, or leaf blight, yield is affected. Our current field plots, managed with the revised fungicide schedule (Table 5) should help to answer these questions.

In our field plots, it was interesting to note the succession of foliar diseases from pre- to post-renovation. Leaf scorch was the predominant disease in the 'Jewel' planting prior to renovation followed by leaf blight in both 2002 and 2003 (Tables 4 and 7). Leaf blight was most evident during the summer months – typical of plantings throughout the northeast. This may be due to the necessity for a 'heat shock' to stimulate symptom development (Nita et al., 2003). Nonetheless, this has implications for disease management. Specifically, fungicides schedules may have to be tailored to the predominant disease. Again, our redesigned fungicide schedules (Table 5) will provide a better understanding of what growers could expect with early versus late season programs targeted to foliar disease management.

However, it is thought, perhaps erroneously, that foliar disease epidemics initiated prior to harvest are inconsequential and, implicitly, so are early-season fungicide schedules. Indeed, Mutisya and Sullivan (1994) inoculated plants only after renovation; specifically during flower bud formation. Aside from the defoliation studies by Kerkhoff et al. (1988), it is still largely unknown what effects foliar diseases have when epidemics occur early in the season – a typical scenario for leaf scorch. This year we initiated a study investigate the time of infection and severity of leaf scorch on yield parameters (blossom, fruiting spur and fruit number and weight). Inoculations with *Diplocarpon earlianum* started 6 weeks after planting and continued on a biweekly schedule through September (see Table 8). Plants were protected in a screenhouse after inoculation to prevent any further infections from occurring. Plants were moved to an indoor cold storage facility until spring 2004 where they will be planted in the field for flowering and fruiting. Numbers of flower spurs, flowers and fruit per spur, and total fruit weight will be recorded for each individual plant at harvest. Biomass harvest and crown counts will be done at renovation, as previously cited above.

To conclude, we made significant advancements in addressing the objectives we proposed. However, much of what was accomplished in the first 2 years was developing and refining experimental procedures to answer the questions we posed. In this sense, we were quite successful. The current protocols for culturing, inoculation, and measuring photosynthesis have allowed us to design complicated experiments (as just discussed above). Our experience in manipulating disease in field plots has also greatly improved. We hope that the NY IPM Program will take this in to consideration when we apply for additional funding to continue this work.

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Table 1. Mean berry weight, biomass, and crown count per plot for Jewel strawberry plots in Ithaca, NY exposed to various fungicide treatments. Values represent the mean from 6 replicate plots from berries harvested in 2001 and 2002. Values followed by a common letter are statistically equivalent.

<i>Treatment</i>	2001 (2 nd harvest)	2002 (3 rd harvest)		
	Berry weight (kg)	Berry weight (kg)	Biomass (kg)	Crown count
Captan 0.16 lb/A	8.00 a	7.71 a	0.56 a	58 a
Captan 0.5 lb/A	8.71 a	7.80 a	0.51 a	66 a
Captan 1.5 lb/A	8.30 a	8.34 a	0.54 a	61 a
Nova 0.25 oz/A	9.39 a	8.34 a	0.60 a	62 a
Nova 1.0 oz/A	8.95 a	8.44 a	0.59 a	61 a
Nova 2.5 oz/A	8.32 a	8.37 a	0.61 a	64 a
Control	9.33 a	8.32 a	0.60 a	53 a

Table 2. Mean incidence of leaf blight, leaf spot, and leaf per plot for Jewel strawberry plots in Ithaca, NY exposed to various fungicide treatments. Values represent the mean from 6 replicate plots from berries harvested in 2001 and 2002. Values followed by a common letter are statistically equivalent.

<i>Treatment</i>	Autumn 2001			Harvest 2002			Autumn 2002		
	Leaf Blight	Leaf Spot	Leaf Scorch	Leaf Blight	Leaf Spot	Leaf Scorch	Leaf Blight	Leaf Spot	Leaf Scorch
Captan 0.165 lb/A	42.7 ab	0.0 a	0.0	83.5 a	0.0 a	0.0 a	48.6 a	1.0 a	0.6 a
Captan 0.5 lb/A	49.5 ab	0.0 a	0.0	71.8 ab	0.0 a	0.4 a	45.6 a	0.3 a	0.2 a
Captan 1.5 lb/A	46.0 ab	0.0 a	0.0	63.3 b	0.0 a	0.2 a	47.5 a	0.2 a	1.0 a
Nova 0.25 oz/A	44.9 ab	0.2 a	0.0	73.8 ab	0.3 a	0.4 a	38.1 a	0.8 a	0.0 a
Nova 1.0 oz/A	32.2 b	0.2 a	0.0	76.5 ab	0.0 a	0.4 a	45.9 a	0.8 a	0.2 a
Nova 2.5 oz/A	35.3 b	0.9 a	0.0	71.8 ab	0.0 a	0.8 a	37.0 a	0.5 a	0.0 a
Control	54.9 a	0.0 a	0.0	79.2 ab	0.0 a	0.0 a	45.4 a	0.0 a	0.2 a

Table 3. Mean berry weight, biomass, and crown count per plot for Kent and Jewel strawberry plots in Geneva, NY exposed to various fungicide treatments. Values represent the mean from 6 replicate plots from berries harvested in 2002 and 2003. Values followed by a common letter are statistically equivalent.

	2002 (1 st harvest)			2003 (2 nd harvest)		
	Berry weight (kg)	Biomass (kg)	Crown count	Berry weight (kg)	Biomass (kg)	Crown count
<i>KENT</i>						
Captan 0.165 lb/A	5.93 a	0.55 a	70 a	5.08 ab	0.59 a	75 a
Captan 0.5 lb/A	5.88 a	0.52 a	66 a	4.67 ab	0.56 a	69 a
Captan 1.5 lb/A	5.39 ab	0.53 a	76 a	5.57 b	0.66 a	80 a
Nova 0.25 oz/A	4.35 b	0.54 a	71 a	4.53 ab	0.53 a	58 a
Nova 1.0 oz/A	5.46 ab	0.56 a	71 a	4.65 ab	0.51 a	57 a
Nova 2.5 oz/A	4.77 ab	0.50 a	66 a	3.72 a	0.57 a	57 a
Control	5.11 ab	0.48 a	60 a	4.38 ab	0.46 a	58 a
<i>JEWEL</i>						
Captan 0.165 lb/A	7.27 a	0.50 b	73 a	4.49 a	0.49 a	51 a
Captan 0.5 lb/A	7.55 a	0.68 a	59 a	4.76 a	0.45 a	56 a
Captan 1.5 lb/A	6.79 a	0.56 ab	69 a	4.39 a	0.52 a	46 a
Nova 0.25 oz/A	7.51 a	0.56 ab	65 a	4.58 a	0.44 a	50 a
Nova 1.0 oz/A	7.66 a	0.57 ab	67 a	3.88 a	0.47 a	44 a
Nova 2.5 oz/A	7.79 a	0.50 b	65 a	4.53 a	0.41 a	54 a
Control	7.04 a	0.50 b	66 a	4.51 a	0.46 a	53 a

*Yield based on 72 ft row (six 12 ft plots)

Table 4. Mean incidence of leaf blight, leaf spot, and leaf per plot for Kent and Jewel strawberry plots in Geneva, NY exposed to various fungicide treatments. Values represent the mean from 6 replicate plots from berries harvested in 2002 and 2003. Values followed by a common letter are statistically equivalent.

	Harvest 2002				Autumn 2002			
	Leaf Blight	Leaf Spot	Leaf Scorch	Total disease	Leaf Blight	Leaf Spot	Leaf Scorch	Total disease
KENT								
Captan 0.165 lb/A	4.9 a	0.5 a	4.6 a	10.0 a	17.4 a	0.8 a	14.8 a	33.0 a
Captan 0.5 lb/A	2.7 a	0.9 a	7.8 a	11.4 a	11.1 a	0.3 a	0.3 a	11.7 a
Captan 1.5 lb/A	5.0 a	1.0 a	5.2 a	11.2 a	11.1 a	0.8 a	9.5 ab	21.4 a
Nova 0.25 oz/A	1.3 a	0.0 a	4.1 a	5.4 a	10.5 a	0.9 a	13.0 ab	24.4 a
Nova 1.0 oz/A	7.3 a	0.0 a	0.9 a	8.2 a	10.1 a	2.5 a	9.8 ab	22.4 a
Nova 2.5 oz/A	2.4 a	1.1 a	4.3 a	7.8 a	14.3 a	0.9 a	8.6 ab	23.8 a
Control	1.3 a	0.3 a	1.7 a	3.3 a	14.0 a	0.5 a	7.9 ab	22.4 a
JEWEL								
Captan 0.165 lb/A	1.9 a	1.6 a	61.0 a	64.5 a	25.6 ab	1.0 a	0.0 a	26.6 ab
Captan 0.5 lb/A	4.9 a	0.2 a	58.7 a	63.8 a	39.1 ab	0.2 a	0.0 a	39.3 ab
Captan 1.5 lb/A	10.3 a	0.2 a	57.5 a	68.0 a	42.2 a	0.0 a	0.0 a	42.2 a
Nova 0.25 oz/A	7.1 a	0.5 a	57.1 a	64.7 a	19.0 b	0.6 a	0.0 a	19.6 b
Nova 1.0 oz/A	11.6 a	0.5 a	59.2 a	71.3 a	29.8 ab	1.1 a	0.3 a	31.2 ab
Nova 2.5 oz/A	1.4 a	1.6 a	55.9 a	58.9 a	30.8 ab	0.5 a	0.0 a	31.3 ab
Control	4.6 a	0.6 a	51.1 a	56.3 a	35.9 ab	0.5 a	0.0 a	36.4 ab

Table 5. Modified fungicide program for Kent and Jewel plantings, Geneva, NY, 2003.

Treatment	Timing	No. of Applications	Projected Foliar Disease Level
1. Cabrio EC	Pre bloom	2	LOW Full season
then Switch + Captan 50W	Bloom	2-4	
then Cabrio EC	Post renovation	2	
then Nova 40WP	Post renovation	4	
2. Cabrio EC	Pre bloom	2	MEDIUM Early spring
then Switch + Captan 50W	Bloom	2-4	
3. Switch + Captan 50 WP	Bloom	2-4	MEDIUM Post-renovation
then Cabrio EC	Post renovation	2	
then Nova 40WP	Post renovation	4	
4. Switch + Captan 50W	Bloom	2-4	HIGH Grower standard

Table 6. Mean berry weight, biomass, and crown count per plot for Kent and Jewel strawberry plots in Geneva, NY exposed to fungicide treatments outlined in Table 5. Values represent the mean from 10 replicate plots from berries harvested in 2003. Values followed by a common letter are statistically equivalent.

	KENT				JEWEL			
	Berry wgt (kg)	Berry number	Biomass (kg)	Crown count	Berry wgt (kg)	Berry number	Biomass (kg)	Crown count
Whole season	4.72 a	451 a	0.59 a	67 a	4.32 a	421 a	0.44 a	52 a
Pre-Bloom	4.70 a	418 a	0.46 a	54 a	4.51 a	438 a	0.45 a	50 a
Post-Bloom	4.70 a	468 a	0.58 a	70 a	4.52 a	428 a	0.52 a	49 a
Grower standard	4.42 a	453 a	0.59 a	68 a	4.54 a	464 a	0.44 a	52 a

*Yield based on 120 ft row (Ten 12 ft plots)

Table 7. Mean incidence of leaf blight, leaf spot, leaf scorch, and angular leaf spot (ALS) per plot for Kent and Jewel strawberry plots in Geneva, NY exposed to fungicide treatments outlined in Table 5. Values represent the mean from 10 replicate plots from berries harvested in 2003. Values followed by a common letter are statistically equivalent.

	Harvest 2003					Autumn 2003				
	Leaf Blight	Leaf Spot	Leaf Scorch	ALS	Total	Leaf Blight	Leaf Spot	Leaf Scorch	ALS	Total
KENT										
Whole season	1.6 a	0.7 a	8.5 a	1.5 a	12.3 b	2.3 a	0.2 a	17.3 b	0.7 a	20.5 b
Pre-Bloom	1.8 a	0.2 a	9.0 a	0.8 a	11.8 b	1.1 ab	0.5 a	17.3 b	0.0 a	18.9 b
Post-Bloom	2.6 a	0.7 a	10.9 a	1.1 a	15.3 ab	1.1 ab	0.6 a	26.7 ab	0.0 a	28.4 ab
Grower standard	3.1 a	0.9 a	13.5 a	1.1 a	18.6 a	0.3 b	0.3 a	33.7 a	1.1 a	35.4 a
JEWEL										
Whole season	2.7 a	0.7 a	11.7 a	0.0 a	15.1 a	8.3 a	0.7 a	2.3 b	0.0 a	11.3 d
Pre-Bloom	3.5 a	1.4 a	13.2 a	0.7 a	18.8 a	21.7 c	0.3 a	8.2 a	0.0 a	30.2 c
Post-Bloom	4.9 a	1.0 a	14.7 a	0.0 a	20.6 a	12.4 b	0.6 a	6.6 a	0.0 a	19.6 b
Grower standard	4.4 a	1.1 a	13.2 a	0.0 a	18.7 a	30.8 c	0.1 a	9.8 a	0.0 a	40.7 a

Table 8. Treatment outline for greenhouse/ screen house yield study with *D. earlianum*, 2003-2005.

Week	Infection date	Plant age at infection	Leaf wetness (number of plants)					Total plants
			0 Hours	24 Hours	48 Hours	72 Hours	96 Hours	
1	6/1/03	6 weeks	10	10	10	10	10	50
2	6/16/03	8 weeks	10	10	10	10	10	50
3	6/30/03	10 weeks	10	10	10	10	10	50
4	7/16/03	12 weeks	10	10	10	10	10	50
5	7/28/03	14 weeks	10	10	10	10	10	50
6	8/11/03	16 weeks	10	10	10	10	10	50
7	8/25/03	18 weeks	10	10	10	10	10	50
8	9/9/03	20 weeks	10	10	10	10	10	50
9	9/19/03	22 weeks	10	10	10	10	10	50

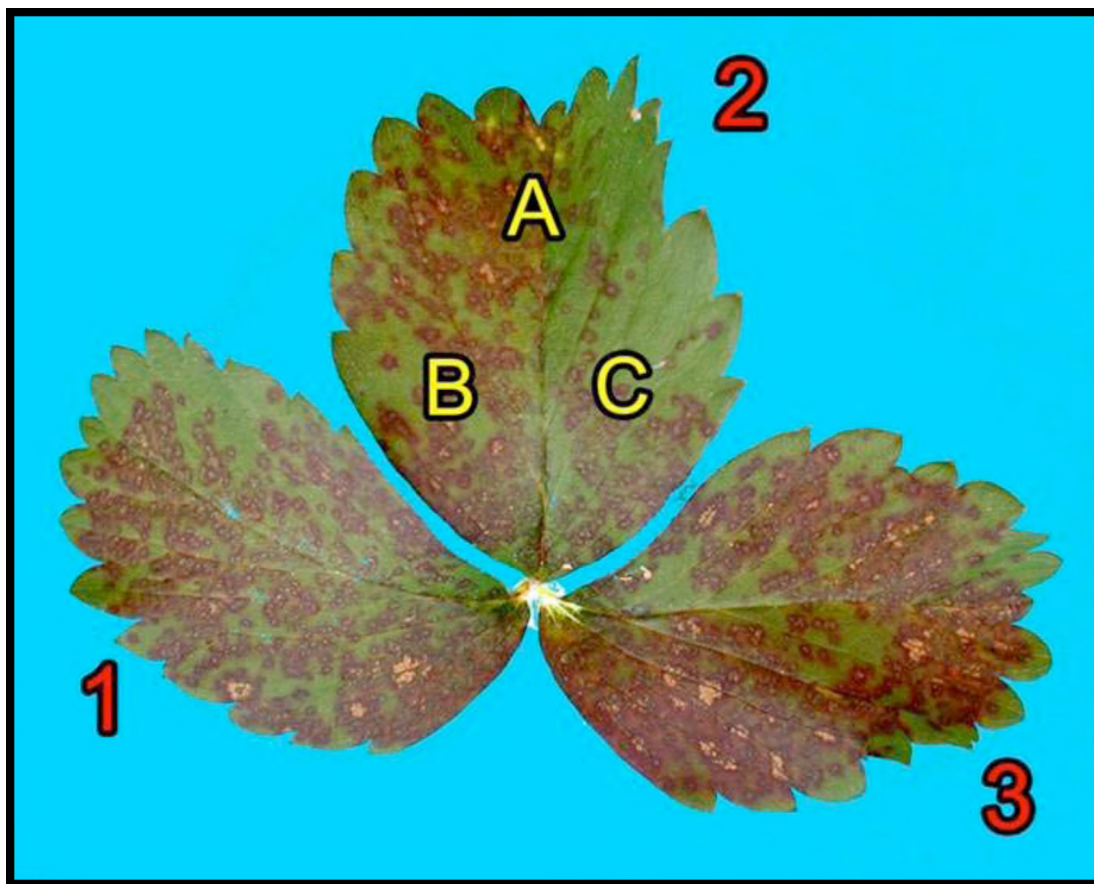


Figure 1. Schematic of the photosynthesis measurement positions referenced in the text.

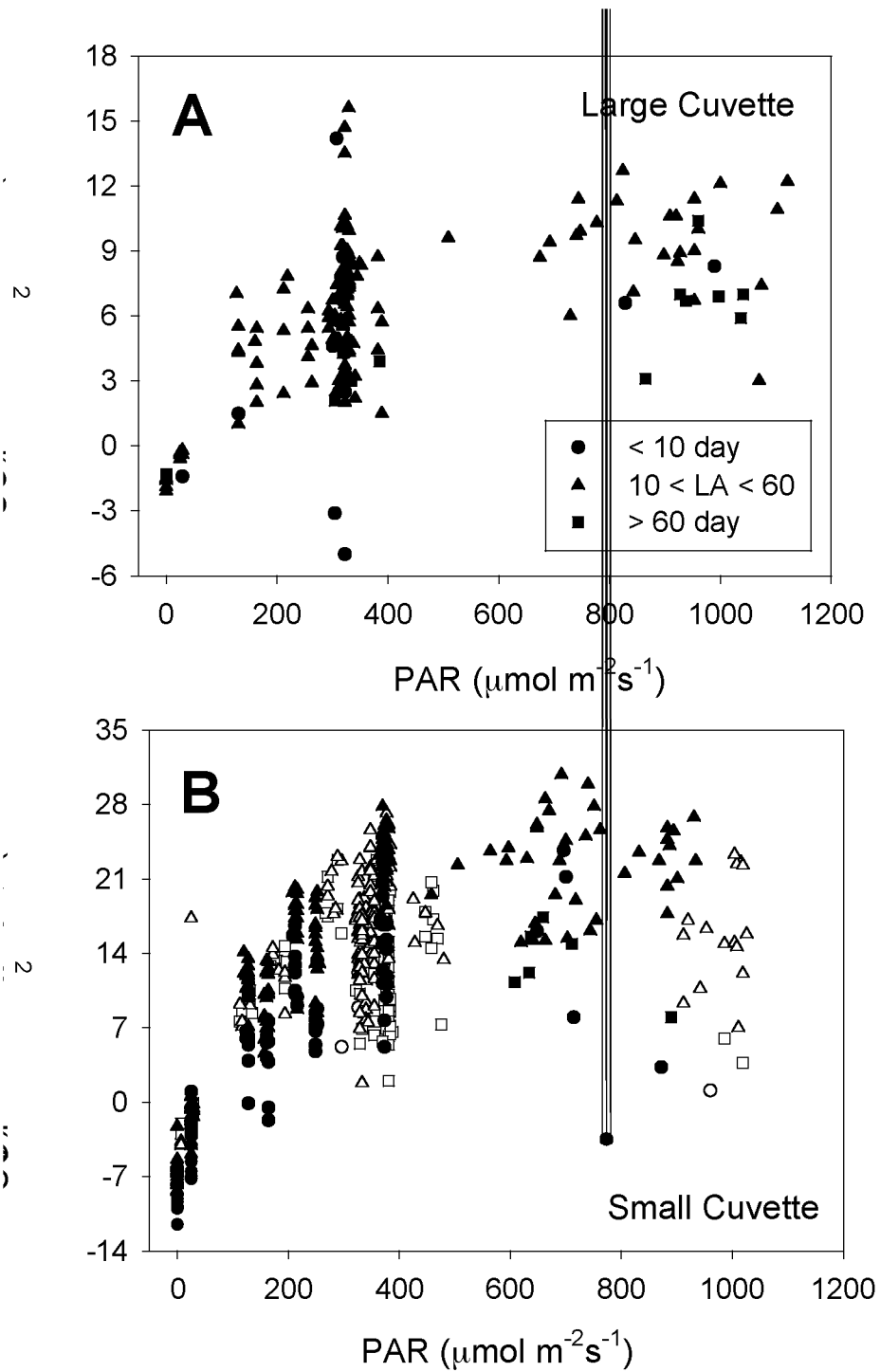


Figure 2. Relationship between rate of CO₂ assimilation (A) and irradiance (i.e., photosynthetically active irradiation) for cultivars 'Jewel' (closed bullets) and 'Kent' (open bullets) for the A, large and B, small cuvettes. Leaf age categories are represented by variously shaped bullets.

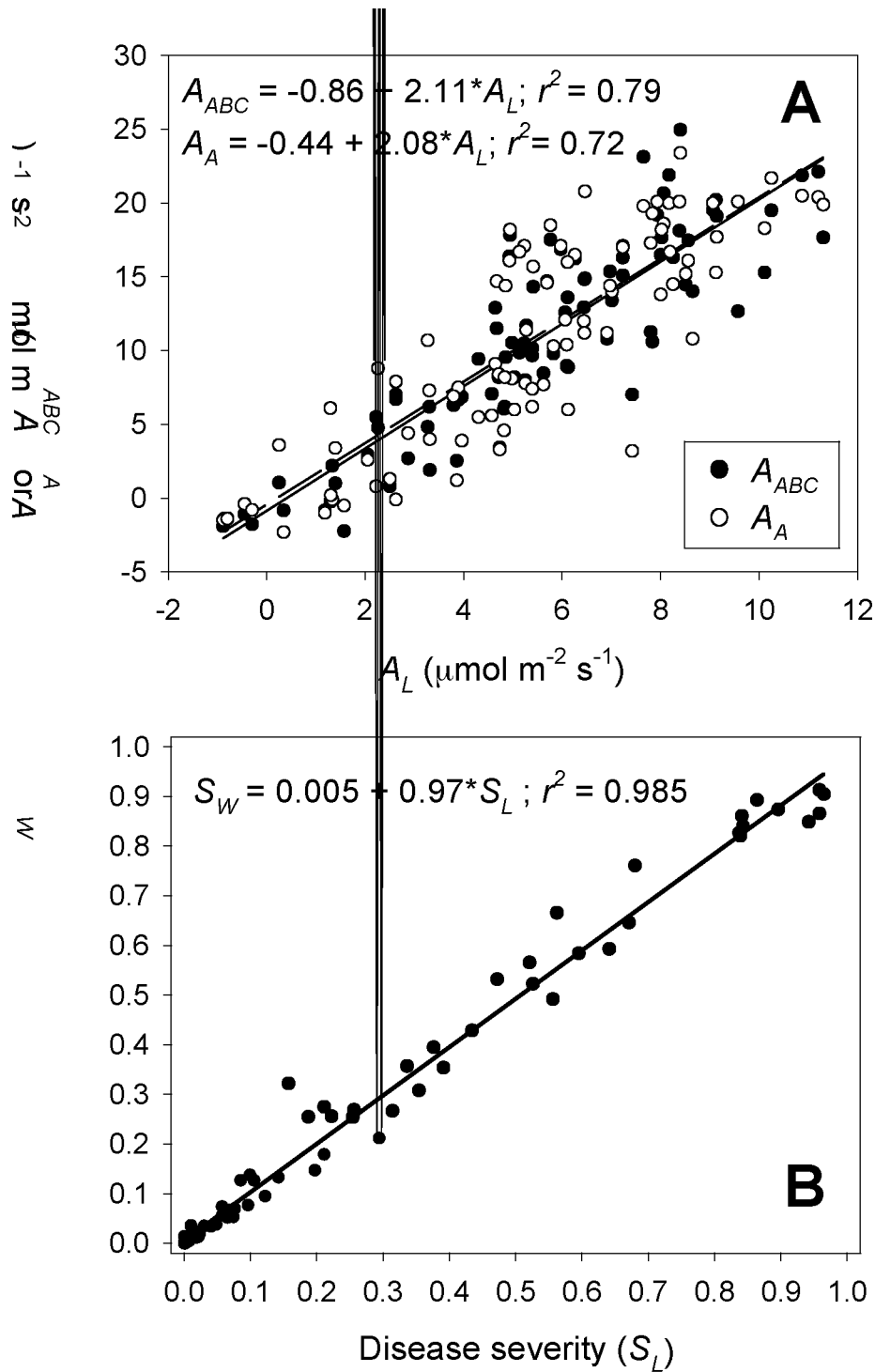


Figure 3. **A**, Relationship between rates of CO₂ assimilation (A) taken with the large cuvette (A_L) and corresponding measurements taken with the small cuvette either as a single measurement (A_A ; open symbol) or an average of three measurements on a single leaflet (A_{ABC} ; closed symbols). **B**, The relationship between leaf scorch severity within area enclosed by the chamber of the large cuvette and actual severity of the same entire leaflet. All measurements were taken on leaflets of 'Kent' plants infected with *Diplocarpon earlianum*.

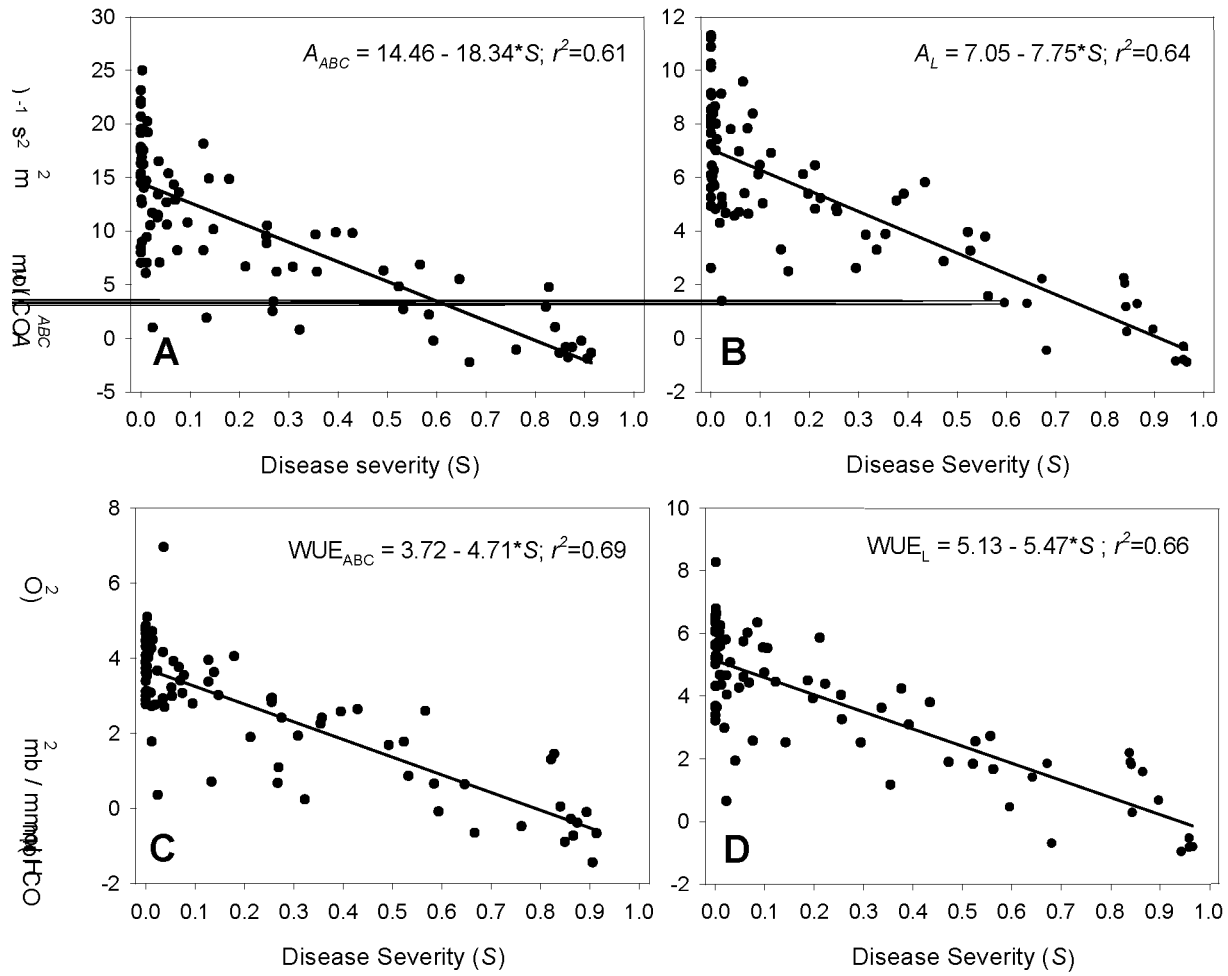


Figure 4. Relationship between rate of CO_2 assimilation (A) and water use efficiency (WUE), calculated as A/E , and S for measurements taken with the large cuvette (A_L , WUE_L) or as an average of three readings taken with the small cuvette (A_{ABC} , WUE_{ABC}) for 'Kent' plants affected with leaf scorch (*Diplocarpon earlianum*).

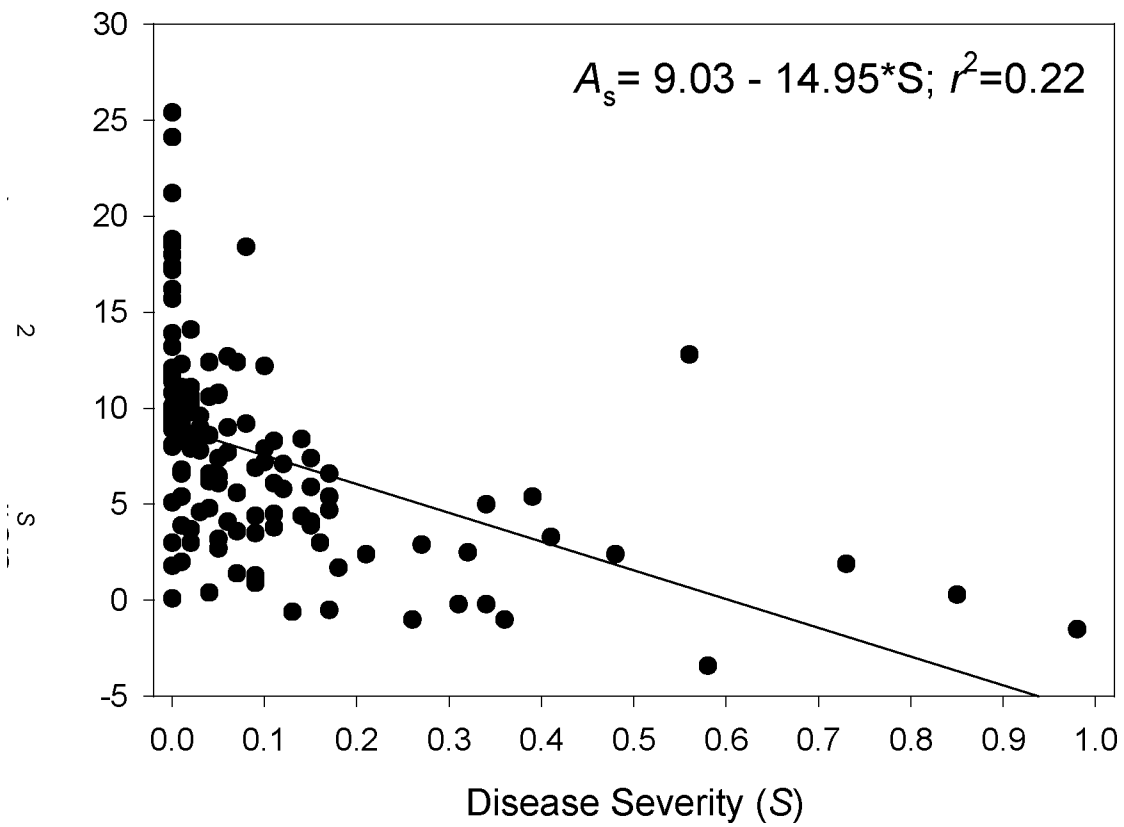


Figure 5. Relationship between rate of CO₂ assimilation (*A*) and *S* for 'Kent' plants affected with leaf spot (*Mycosphaerella fragariae*).